Using Data Visualisation to Explore the Historical Trends in Global Temperatures over Time

It is no secret that planet earth is warming as a consequence of human behaviour. Hansen et al. in “Global surface temperature change” (2010) firmly establishes that despite year-to-year temperature fluctuations from tropical ocean temperature cycles, global temperatures in the decade up to 2010, rose faster than in the prior two decades. That being said, to gain a more comprehensive understanding of global warming, a deeper analysis can be conducted. This includes exploring questions such as which areas of the world are most affected, what the normal temperature variations were before climate change, the extent of climate change's variability (how much temperatures can swing over time away from the norm), and which seasons have been most affected. Although the scientific community has extensively investigated these topics, I aim to use climate models to add value in this exploration. As Edwards states in “Simulation Models and Atmospheric Politics” (2010), simulation models in atmospheric science offer insights into temperature changes by simulating complex processes and aiding predictions about future climate scenarios. Frigg et al. (2023) adds to this in their article “Philosophy of climate science” stating that climate models are used by centres like NASA, the UK Met Office, and the Beijing Climate, to guide policy decisions, stimulate technological innovation and foster a collective response to combat climate change. However, The article also cautions that the uncertainties about future greenhouse gas emissions can make it challenging for these models to generate accurate future predictions. This is where the importance of generating historical data with models and employing data visualisation techniques becomes critical. The article "Apocalypse Forever? " by Swyngedouw (2010) emphasises the use of apocalyptic imaginaries and populist gestures in the presentation of climate change, suggesting that it is staged in a dramatic and attention-grabbing manner. By simulating and visualising historical data, free from emotive rhetoric and dramatic portrayals, we can uncover hidden patterns, correlations, and trends about our past that can inform policymakers to make good decisions about our future.

The dataset “NCAR CESM2 model output prepared for CMIP6 CMIP historical," (Danabasoglu, 2019) was published in 2019 by Danabasoglu from the National Centre for Atmospheric Research (NCAR). This dataset is data generated by the Community Earth System Model 2 (CESM2), a state-of-the-art climate model developed by NCAR for the Coupled Model Intercomparison Project Phase 6 (CMIP6) experiment. CESM2 is a sophisticated tool that combines different aspects of the Earth's environment to study and predict historical climate conditions. According to Danabasoglu et al. (2020), it uses detailed models for weather patterns, ocean currents, and ice movements, that work together to give a full picture of how our planet's climate works and how it has changed over time, taking into account human influences like greenhouse gas emissions and land use changes. The specific dataset I used from the CESM2 experiment was designed to predict surface air temperatures dating back to 1850, with the generation process of this data likely spanning several years before its 2019 publication (CESM Experiments, n.d.). An article by Hagi (2020) provided me with guidance on how to access this data in Jupiter notebooks. To see how I used this code to extract, manipulate, and visualise the data, kindly refer to my GitHub repository, 10743794 (2023), where I have documented the code I used in a Jupyter notebook to make my visualisations in this essay.

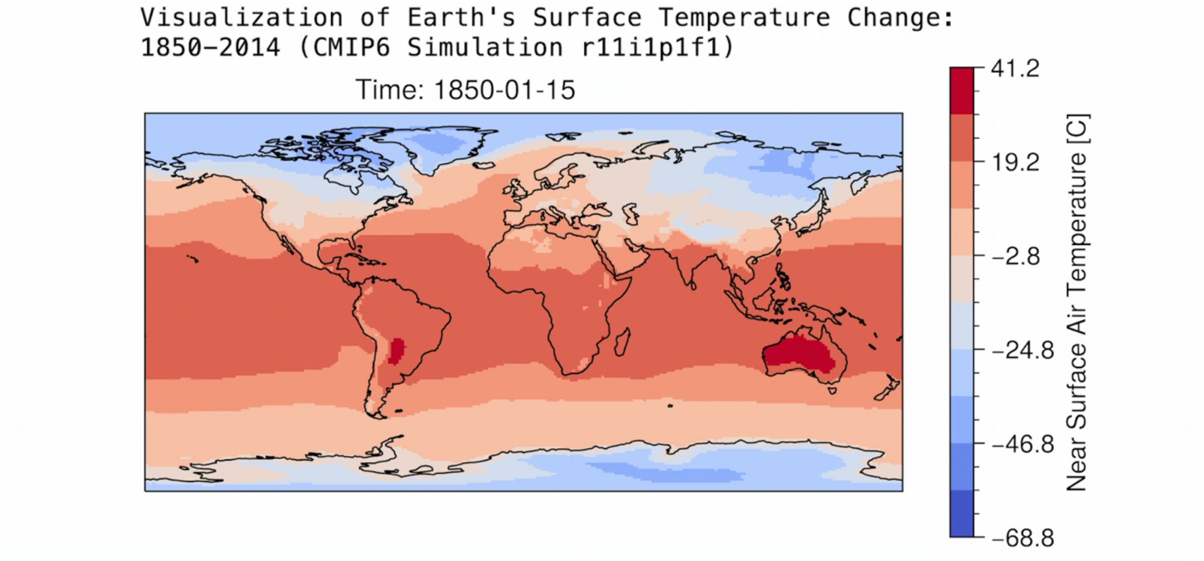

Figure 1: A map to show the earth's surface temperature at any given month. To see a video of the map animating, Please click this link https://www.youtube.com/watch?v=-8A-EFdUuFs

To understand the change in temperature over time, I visualised the "tas" variable from the dataset, which represents the near-surface air temperature in Kelvin, at a certain time, at a certain latitude and longitude on the earth's surface (see Figure 1). Longitudinal data like this allows scientists to observe geographical patterns and trends in global temperatures. In his work, Tufte (1983) emphasises the importance of graphs focusing on data representation over aesthetic or design elements. My graph reflects this ethos through its simplicity. I projected the temperature data to a simple cylindrical colourmap and the colourbar was added to indicate the temperature. Drawing from Imhoff's "Cartographic Relief Presentation" (2007), I used a 12°C interval colourbar to highlight temperature anomalies, with muted colour contrasts of complementary reds and blues for an attractive differentiation between warm and cool temperatures. To enhance understanding, I converted the "tas" temperature data from Kelvin to Celsius by deducting 273.15. Inspired by Kwan's animated work in "Affecting geospatial technologies" (2007), I animated the map to show changing temperatures over time, allowing quick visual analysis of overarching patterns across many images. This map is depicts normal seasonal climate patterns before climate change and how these seasonal patterns changed to become more extreme as a result of climate change. The map shows the subtlety of climate change, as the yearly changes in temperature patterns are minimal in this visual. However, the graph presents a few challenges. Primarily, it is difficult to discern correlations between yearly increases in temperature, as the yearly increases in temperature due to climate change are relatively minor compared to the overall scale of temperature readings and seasonal changes. This subtlety makes it hard to visually capture the long-term trends of climate change, as the more substantial seasonal fluctuations in temperature tend to overshadow the smaller, gradual changes related to yearly changes in global temperature warming.

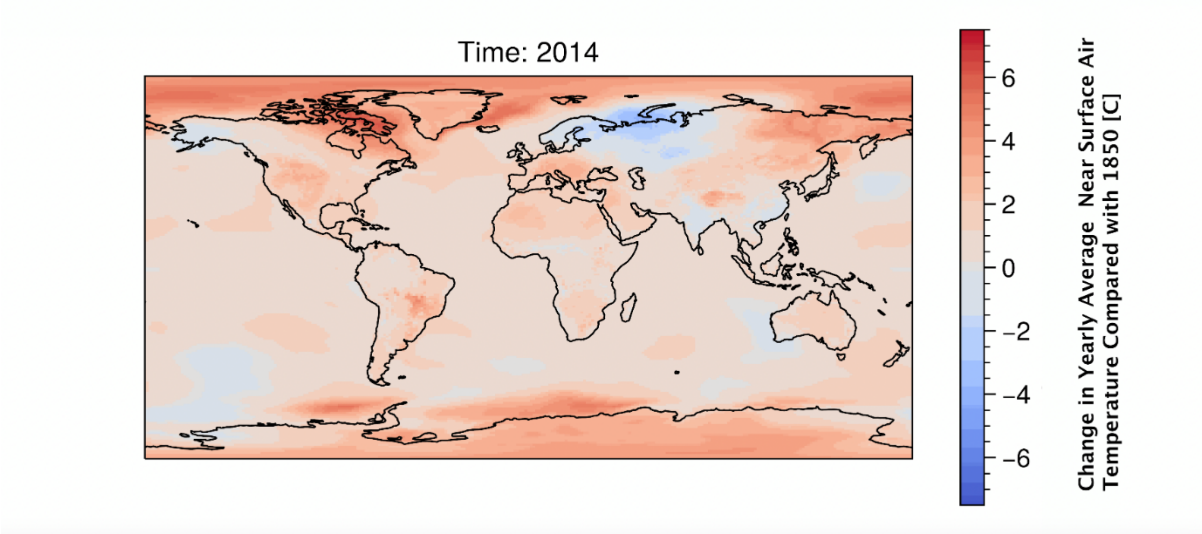

Figure 2: A map to show the earth's Yearly Average Near Surface Air Temperature Change Compared with 1850. To see a video of the map animating with a comparison to figure 1, Please click this link https://www.youtube.com/watch?v=zUuyePLL3rw

To address these limitations and offer a clearer picture of long-term climate change, I created Figure 2 to depict the annual average near-surface air temperature changes relative to 1850. Hansen et al (2010) suggests using a 12-month running mean temperature to remove the annual cycle and provide a clearer representation of long-term temperature trends. Therefore, in line with Hansen et al. (2010), the second map utilises a 12-month running mean temperature for clarity. I resampled the original monthly dataset to yearly frequency by taking the average temperature of each year from the monthly data. I then computed the average temperature for the year 1850 and subtracted this baseline from the temperature of all subsequent years to get the change in temperature. The data was then normalised to create a diverging colormap cantered around the temperature 0°C. This map uses the same cool-warm colour scheme, but this time, the colours represent temperature change instead of the actual temperature. The scale for this colourbar is therefore smaller than Figure 1, allowing for a more detailed and sensitive portrayal of temperature changes. Tufte (1983) emphasises that a well-designed graph should reveal many layers of data. This graph does this by not only showing temperature change over time, but also the rate of change, the areas most affected, the progression of temperature change, the variability of change over time, and the temperature patterns before climate change. The temperature patterns before climate change can be seen by looking at the graph from around 1850-1950. The shift towards warmer colours becoming more pronounced around the late 20th century, shows an increased pace of global warming during this period, in line with Hansen et al.'s conclusions. The map's deepening reds and faint blues, particularly in polar regions, indicate an uneven global warming rate, with acceleration in the poles. An escalation colour contrast over time would signify increasing temperature volatility and variability, marking climate change's potential for more frequent, severe weather events. However, this is not obvious to see in Figure 2.

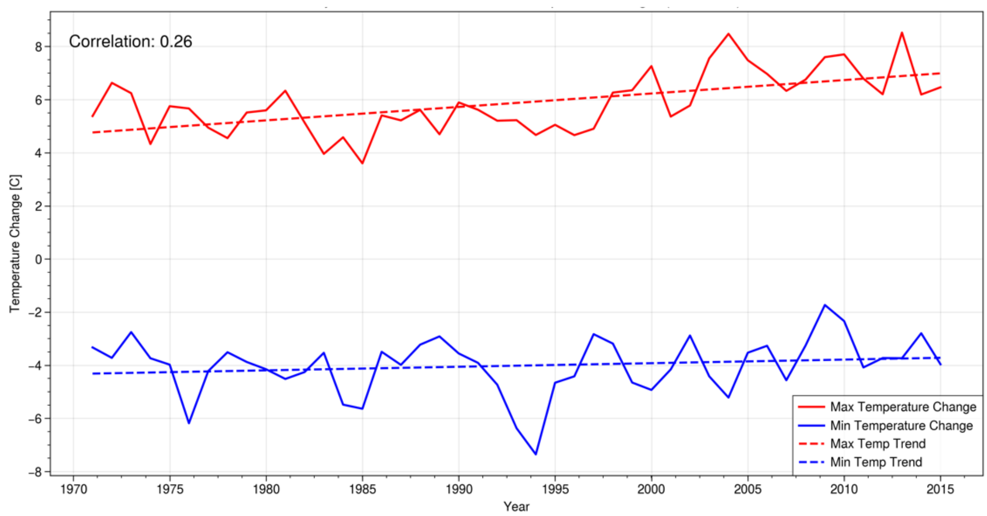

Figure 3: Historical Trends in Annual Extremes of Near-Surface Air Temperature changes compared with 1850 (1971–Present)

To enhance our understanding of the variability of extreme temperatures in this climate dataset, I developed Figure 3. This visualisation focuses on the historical trends in annual extremes of near-surface air temperature changes, starting from 1971— a point in time when the impacts of climate change begin to emerge more distinctly in Figure 2. The graph displays a dual-line chart that contrasts the temperature change from 1850 of the hottest location in a given year with that of the coldest location from the same year, facilitating a straightforward comparative analysis over time. Trend lines highlight the long-term shifts, making apparent the rising temperature trend and the growing gap between hot and cold extremes. The steeper ascent of the Max Temperature Change line, in comparison to the Min Temperature Change, suggests that maximum temperatures are rising at a more rapid pace. This divergence implies a broadening range between temperature extremes, which could lead to more pronounced seasonal variations and potentially exacerbate the effects of climate change.

In conclusion, these visualisations offer a compelling narrative of the historical trends in global temperatures, highlighting the areas most impacted by warming, the extent of climate change's variability, and the seasonal changes in temperature. Counter to Swyngedouw's (2010) focus on apocalyptic visuals, Figure 1 highlights the subtle and incremental progression of climate change. While it is difficult to pinpoint the exact year when the climate began to change, Figures 2 and 3 clearly illustrate the overall warming trend and the increasing gap between temperature extremes. These insights can inform future mitigation strategies. The years from 1850-1950 on Figures 1 and 2 show what temperature patterns used to look like, offering policymakers a clear target to aspire to in climate regulation efforts. A limitation of these visualisations is their inability to specify the exact year of the onset of climate change, yet the broader implications of the observed long-term trends are unmistakable. Future work should focus on refining these models to better identify the initial shifts in climate patterns, thereby enhancing our understanding of climate dynamics and informing more targeted policy interventions.

(1639 words)

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